A MECHANISM FOR MASS EJECTION IN RED GIANTS*

In a recent paper, Weymann (1962b) has discussed various mechanisms which have been proposed for the ejection of matter from red giants such as α Orions. The main difficulty is to explain the observed apparently constant out-flow of matter beyond 10 stellar radii with a speed ~ 10 km sec^{-1}. which is less than the escape velocity from the star (Weymann 1962a). Purely hydrodynamic theories seem to demand an extensive hot corona surrounding the star for which no observational evidence is available.

A simple explanation of the observations seems possible if solid particles, on which radiation pressure can act, are able to condense. Weymann (1962b) discusses this possibility briefly but is led to reject it, partly on account of the lack of plausibility of the idea that ice-like grains can condense in the envelope at 1000 K and partly on account of a large drift velocity which he obtains for the ice grains relative to the gas. The same conclusions, however, do not appear to hold for the case of graphite particles of sizes $\sim 3.10^{-6}$ cm.

Donn, Wickramasinghe, Stecher, and Hudson (1965) have recently considered the possibility that graphite particles of sizes required to explain the interstellar extinction (Wickramasinghe and Guillaume 1965, Stecher and Donn 1965) may condense in the expanding envelopes of red

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$$k = \frac{x \rho_c}{\frac{4}{3} \pi a^3 s} \pi a^2 Q_{ext} \Big/ \rho_H \quad cm^2 \, gm^{-1} \quad , \tag{2}$$

or in terms of number densities with $s \cong 2.5$ gm cm^{-3},

$$k \cong 3.6 \times \frac{n_c}{n_H} a^{-1} Q_{ext} \quad cm^2 \, gm^{-1} \quad . \tag{3}$$

With $n_c/n_H \cong 10^{-3}$, $a = 3.10^{-6}$ cm, and $Q_{ext} \cong 0.5$, we have

$$k \approx 6.10^2 \, x \, cm^2 \, gm^{-1} \quad . \tag{4}$$

Thus, $x \approx 0.01$ (i.e., 1% of the C condensed) would suffice to produce an opacity $k \approx 10$ cm^2 gm^{-1}.

A further requirement to be satisfied is that the gas and grains are not too quickly separated. Let V be the radial drift velocity of the grains relative to the gas. We shall now express the condition that the gravitational force on the gas is balanced by the force exerted by the grains. The mean free path of a gas atom between successive collisions with grains is given by

$$\ell \approx (\pi a^2 n_D)^{-1} \quad , \tag{5}$$

where n_D is the number density of dust grains. The average time interval between two consecutive collisions of a gas atom with grains is therefore $\sim (V \pi a^2 n_D)^{-1}$, and during this time the gas atom acquires a radial momentum $\sim m_H V$. The rate of change of radial momentum per gas atom is therefore $\sim m_H V^2 \pi a^2 n_D$; and equating this to gravity we have

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$$m_H V^2 \pi a^2 n_D \approx m_H g \quad ,$$

$$V \approx (g/\pi a^2 n_D)^{1/2} \quad . \tag{6}$$

Writing

$$n_D = \frac{12 \, m_H \, n_C \cdot x}{\frac{4}{3} \pi a^3 s} \quad ,$$

and substituting numerical values $n_H = 3.10^8$, $n_C/n_H \simeq 10^{-3}$, $s = 2.5$ gm cm^{-3}, and $g \cong 7.10^{-3}$ cm sec^{-2} (at 10 stellar radii), we get

$$V \approx \left(\frac{a}{3 \times 10^{-6}}\right)^{1/2} x^{-1/2} \text{ km sec}^{-1} \quad . \tag{7}$$

For $x \simeq 0.01$, $a = 3 \times 10^{-6}$, the velocity of radial drift of grains relative to the gas is ~ 10 km sec^{-1}, comparable to the radial velocity of the envelope itself. This is considerably less than the velocity ~ 160 km sec^{-1} which Weymann (1962b) gives for micron size ice grains. A drift velocity somewhat less than 10 km sec^{-1} is possible by choosing a larger value of x, that is, supposing that more than 1% of the available carbon condenses as graphite, which is indeed likely. However, the coupling we already have is sufficient to release the envelope matter to infinity. The escape velocity at a distance r from the star is $\sim (GM/r)^{1/2}$, = 20 km sec^{-1} at 10 stellar radii. In order for the envelope to be able to escape, therefore, the matter at 10 stellar radii has to be propelled at 10 km sec^{-1} only up to a further distance ~ 10, perhaps 20 stellar radii before it has enough energy to escape. An envelope of dimension ~ 10 stellar radii will be stripped of dust in a time ~ 20 years. During this time, however, more C would have condensed as graphite to maintain the thermodynamic balance, and the timescale ~ 20 years is sufficient for grains to grow to sizes ~ 3.10^{-6} cm. This process could continue until the gas becomes too tenuous -- i.e., until it gets too far from the star. A given sample of the envelope material is therefore able to escape from the gravitational potential well of the star as a result of grains condensing constantly within it.

A question yet remains as to how the envelope matter is lifted from the photosphere out to a distance of 10 stellar radii. Although the effective temperature of the star is ~ 3400 K, it is not unlikely that the temperature at a scale height above the photosphere may fall to ~ 2100 K during minimum phase permitting the condensation of graphite. However, in these regions grains cannot grow to radii much larger than ~ 10^{-7} cm on account of the large excess of atomic hydrogen present (Donn et al., 1965). From equation (3), with $n_C/n_H \approx 10^{-3}$, it is seen that a very small fraction $x \approx 0.001$ of the available carbon is required in the form of graphite grains with radius 3.10^{-7} cm in order to produce the necessary opacity ~ 10 $cm^2\ gm^{-1}$ to eject the matter. On account of the higher ambient gas density, the grains and gas will be very strongly coupled as they begin to move outward. Significant decoupling would begin to take place when the matter reaches the envelope and the considerations of the earlier paragraphs become valid.

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REFERENCES

Donn, B., Wickramasinghe, N. C., Stecher, T. P., and Hudson, J., 1965, in preparation.

Donn, B. and Stecher, T. P., 1965, Ap. J. in press.

Weymann, R., 1962(a), Ap. J., 136, 844.

Weymann, R., 1962(b), Ap. J., 136, 476.

Wickramasinghe, N. C. and Guillaume, C., 1965, Nature, 207, 366.